

PAPER • OPEN ACCESS

Dependence of the erosion of graphite on flux density for high-temperature irradiation by hydrogen ions

To cite this article: N A Puntakov *et al* 2019 *J. Phys.: Conf. Ser.* **1396** 012035

View the [article online](#) for updates and enhancements.



IOP | ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the **collection** - download the first chapter of every title for free.

Dependence of the erosion of graphite on flux density for high-temperature irradiation by hydrogen ions

N A Puntakov, L B Begrambekov, A V Grunin and G D Dolganov

National Research Nuclear University “MEPhI”, 115409, Moscow, Russia

E-mail: lbb@plasma.mephi.ru

Abstract. In this paper, a dependence of the erosion of graphite under a high energy ion flux at temperature of 2050°C on the ion dose is investigated. It is shown that, at ion flux density of 1.42×10^{22} ion/m²s, irradiation stimulates diffusion processes that lead to the removal of carbon atoms from the bulk of the sample, leading to the formation of a porous layer, whereas, for ion flux density of 1.4×10^{20} ion/m²s, no such layer is formed.

1. Introduction

Utilisation of graphite and carbon composites as plasma-facing materials has played a significant role in the development of thermonuclear research during the period of mastering “long” pulses in tokamaks [1]. Most of currently operating large tokamaks use metals as materials for the first wall and the divertor. Tungsten will be used as such material in the currently constructing International Thermonuclear Experimental Reactor (ITER). Despite that, research conducted in the last few years suggests that the potential of using carbon-based materials in thermonuclear facilities is not yet depleted. As such, the research on a problem of the behavior of graphite under stationary irradiation by high intensity ion flux is of great interest.

In this work, a dose dependent research comparing the behavior of graphite irradiated by ion fluxes of different densities has been conducted. The amount of sputtered material, the influence of ion flux density on processes undergoing in the near-surface layers of graphite are compared, a possible mechanism of the effects of high intensity ion irradiation on the modification of near-surface layers of graphite is discussed.

2. Experimental setup

The experiments on irradiation of small-grain MPG-8 grade graphite were conducted on two facilities: CODMATT [2] and DEKOR [3]. In both stands, the experiments were conducted using ions of hydrogen plasma, undivided by mass and generated between a tungsten glow cathode and an anode. The beam had the following ion content during the experiments: 86% H₂⁺ ions, with the rest being H⁺ and H₃⁺ ions. Ion energy was 14 keV/ion on both stands. The temperature was kept at 1750°C during irradiation. Heating during the experiments was performed by the ion beam directly in CODMATT, and by using a flat tungsten spiral heater mounted behind the sample in DEKOR. The temperature was measured via a pyrometer in both stands. Ion flux density was 1.4×10^{20} ion/m²s for DEKOR. Residual gas pressure during the experiments on DEKOR did not exceed 1×10^{-5} torr. In CODMATT, the ion flux density was 1.42×10^{22} ion/m²s, with the residual gas pressure less than 2×10^{-6} torr.



A depth of the cavern corresponding to the amount of sputtered material was then calculated (L_{massC} and L_{massD} for CODMATT and DEKOR, respectively). The data obtained was then compared to the depth of the sputtered region measured via contact profilometer (L_{surfC} and L_{surfD} for CODMATT and DEKOR, respectively).

3. Results and discussion

The dependencies on figure 1 show that, in case of irradiation by the more intense ion beam, $L_{\text{mass}} > L_{\text{surf}}$ throughout the entire range of irradiation doses, i.e. the amount of sputtered material at for the same dose was higher than the amount of material removed from a crater that formed after the sample was sputtered. This shows that, during that sort of irradiation, carbon atoms are removed not only from the irradiated surface, but also from the bulk of graphite. The atoms diffuse from the bulk of graphite during irradiation to the surface, where they are sputtered. As a result, as shown in [4, 5], pores should form in the near-surface layer.

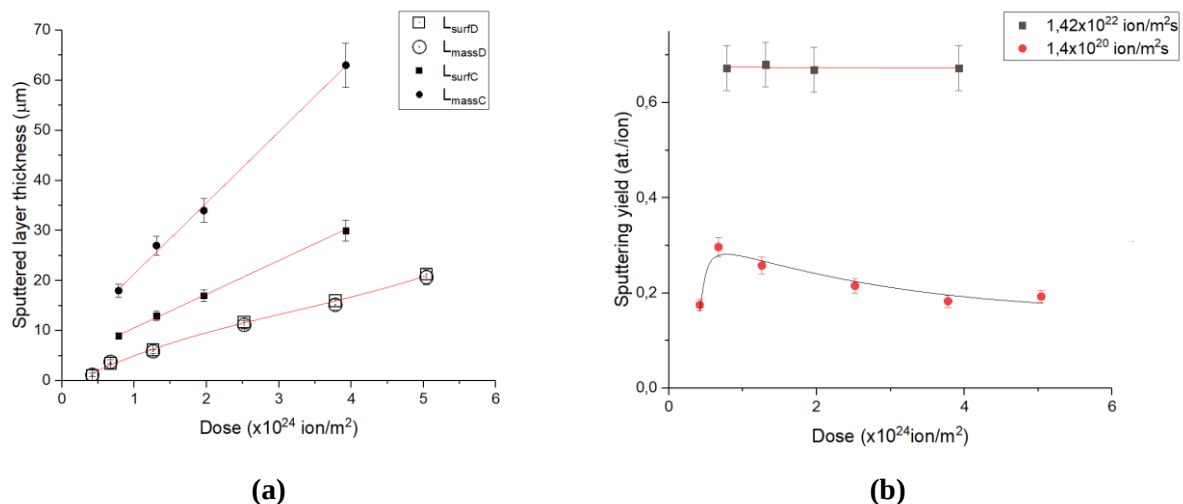


Figure 1. The dependence of: (a) – thickness of sputtered layers corresponding to the amount of removed material (L_{massC} and L_{massD}) and thickness measured by the profilometer (L_{surfC} and L_{surfD}); (b) – sputtering coefficients depending on the dose of irradiation by hydrogen ions with flux densities of 1.4×10^{20} and 1.42×10^{22} ion/m²s.

As seen on figure 1a, difference between L_{massC} and L_{surfC} forms on the initial irradiation dose of 4.26×10^{23} ion/m² and grows linearly with the increase of the dose. As such, the rate of atoms diffusing from the bulk to the surface and their sputtering rate are constant throughout the entire range of irradiation doses.

It is obvious that the thickness of a porous layer is higher than L_{massC} . If we assume the concentration of pores to be constant on the entirety of the layer, its thickness turns out to be twice as much as L_{massC} , being approx. 200 μm at the irradiation dose of 3.93×10^{24} ion/m².

Total amount of sputtered carbon atoms during irradiation by ion flux with a density of 1.4×10^{20} ion/m²s is much less than that for the ion flux density of 1.42×10^{22} ion/m²s. Also, in the former case, the difference between L_{massD} and L_{surfD} is insignificant, which suggests the lack of a significant porous layer in samples irradiated by ions of moderate ion flux densities.

Sputtering coefficients of graphite during irradiation by ions with flux densities of 1.42×10^{22} ion/m²s and 1.4×10^{20} ion/m²s differ by a factor of approx. 4 at the entire range of irradiation doses (figure 1a). At the same time, figure 2a and b show that the porosity and, as such, surface areas of irradiated parts are similar in both modes of irradiation. Thus, it can be concluded that the increase of sputtering coefficient is explained by a lower bonding energy of surface atoms, or a higher rate of surface amorphisation during high intensity irradiation.

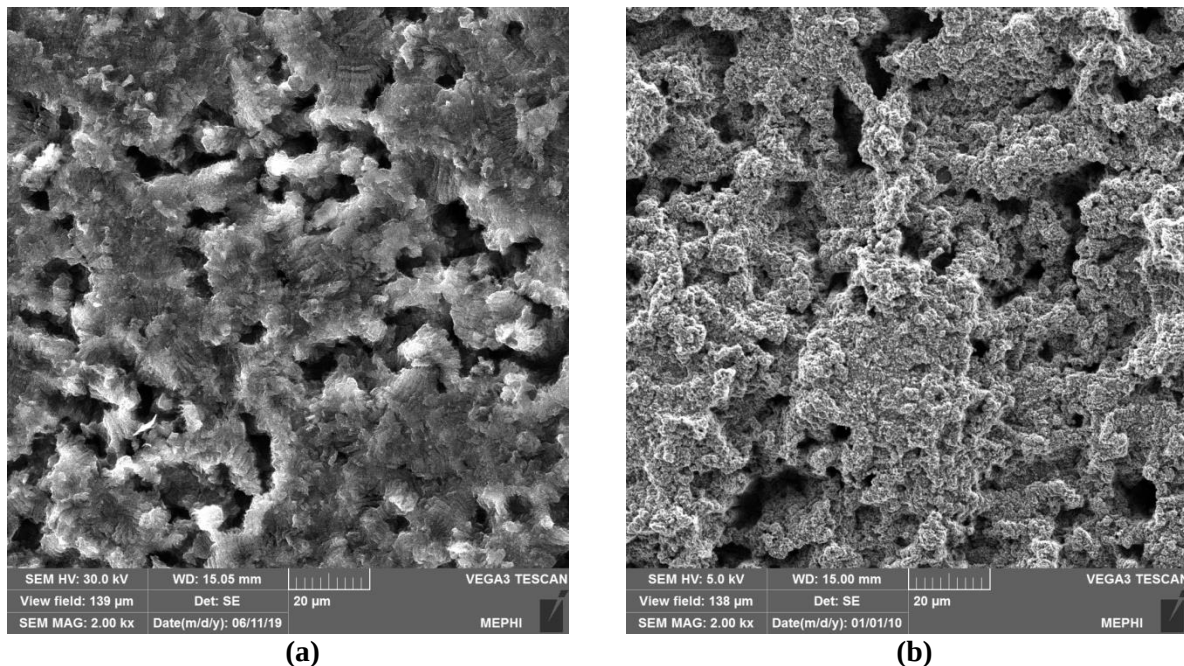


Figure 2. Surface of graphite irradiated by: (a) – hydrogen ions with flux density of 1.4×10^{20} ion/m²s and dose of 3.78×10^{24} ion/m²; (b) – hydrogen ions with flux density of 1.42×10^{22} ion/m²s and dose of 3.93×10^{24} ion/m².

Characteristics described above can be explained by the way diffusion processes occur in graphite. In the structure of graphite, interatomic distance inside a graphene layer and between graphene layers are vastly different (0.14 and 0.34 nm, respectively). As such, the diffusion rate of radiation-induced vacancies along the graphene layers and interstitial atoms between them is much higher than along the directions perpendicular to graphene layers.

It can be assumed that, due to amorphisation of structure in the impact layer of graphite, vacancy diffusion will be predominantly into the bulk. At the same time, structure amorphisation can assist the transport of carbon atoms removed from the lattice by ions into the interstitial lattice to the surface. Combination of these factors, presumably, leads to the development of porosity in the graphite layers beyond the ion impact layers.

At a lower ion flux density, vacancy concentration in the ion impact layer and structure amorphisation are also lower. The difference between the rates of diffusion processes in different directions decreases, and the development of a porous layer is less noticeable.

4. Conclusion

Erosion and of small-grain MPG-8 grade graphite's surface layer under irradiation at temperature of 1750°C by hydrogen ions with the energy of 7 keV and ion flux density of 1.4×10^{20} , as well as 1.42×10^{22} ion/m²s for doses of up to 5.04×10^{24} ion/m² has been investigated.

It was found that a porous layer is formed on the irradiated surface if graphite is treated by a hydrogen ion beam with flux density of 1.42×10^{22} ion/m²s. No such layer was observed when the samples were irradiated by a hydrogen ion flux with a density of 1.4×10^{20} ion/m²s.

It was shown that sputtering coefficient during irradiation by a more dense hydrogen ion flux is larger than that for a less dense ion flux by about a factor of 3.

A proposition is made that graphite irradiation at higher flux density stimulates higher amorphisation of the structure, which leads to the accelerated vacancy diffusion into the bulk of graphite and, consequentially, the formation of porosity.

References

- [1] Khvostenko P P *et al.* 2019 *Fusion Engineering and Design* **146A** 1108–12
- [2] Azizov E, Barsuk V, Begrambekov L, Buzhinsky O, Evsin A, Gordeev A *et al.* 2015 *Journal of Nuclear Materials* **463** 792–5
- [3] Begrambekov L B, Dovganyuk S S, Evsin A E and Kaplevsky A S 2018 *Physics of Atomic Nuclei* **81(11)** 1601–05
- [4] Begrambekov L B, Dolganov G D, Grunin A V, Puntakov N P and Titkova K M 2018 *Journal of Physics: Conference Series* **1121(1)** 012006
- [5] Begrambekov L B, Dolganov G D, Grunin A V, Puntakov N P and Titkova K M 2018 *Journal of Physics: Conference Series* in press